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Introduction to the GeoSAR Radar Interferometric Mapping Instrument

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Overview of GeoSAR

- Aircraft-based, interferometric synthetic aperture radar (SAR) system for topographic mapping.
  - Gulfstream II business jet
  - Day/night, all-weather, low-cost, commercial system
- Develop precision foliage penetration mapping technology based upon dual frequency, dual polarimetric, interferometric radar.
  - X-band radar (λ=3 cm) for bare ground and "tops" of trees
  - P-band (UHF) radar (λ=86 cm) for ground and foliage penetration (HH,HV)
- Produce true ground surface digital elevation models suitable for a wide variety of applications.
  - Combination yields "true ground surface" (TGS)
- Project initially funded by DARPA with current funding by NIMA.
  - Calgis, Inc., Fresno, CA
  - Caltech's Jet Propulsion Laboratory (JPL), Pasadena, CA
  - California Department of Conservation (CalDOC)

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The GeoSAR System Flow

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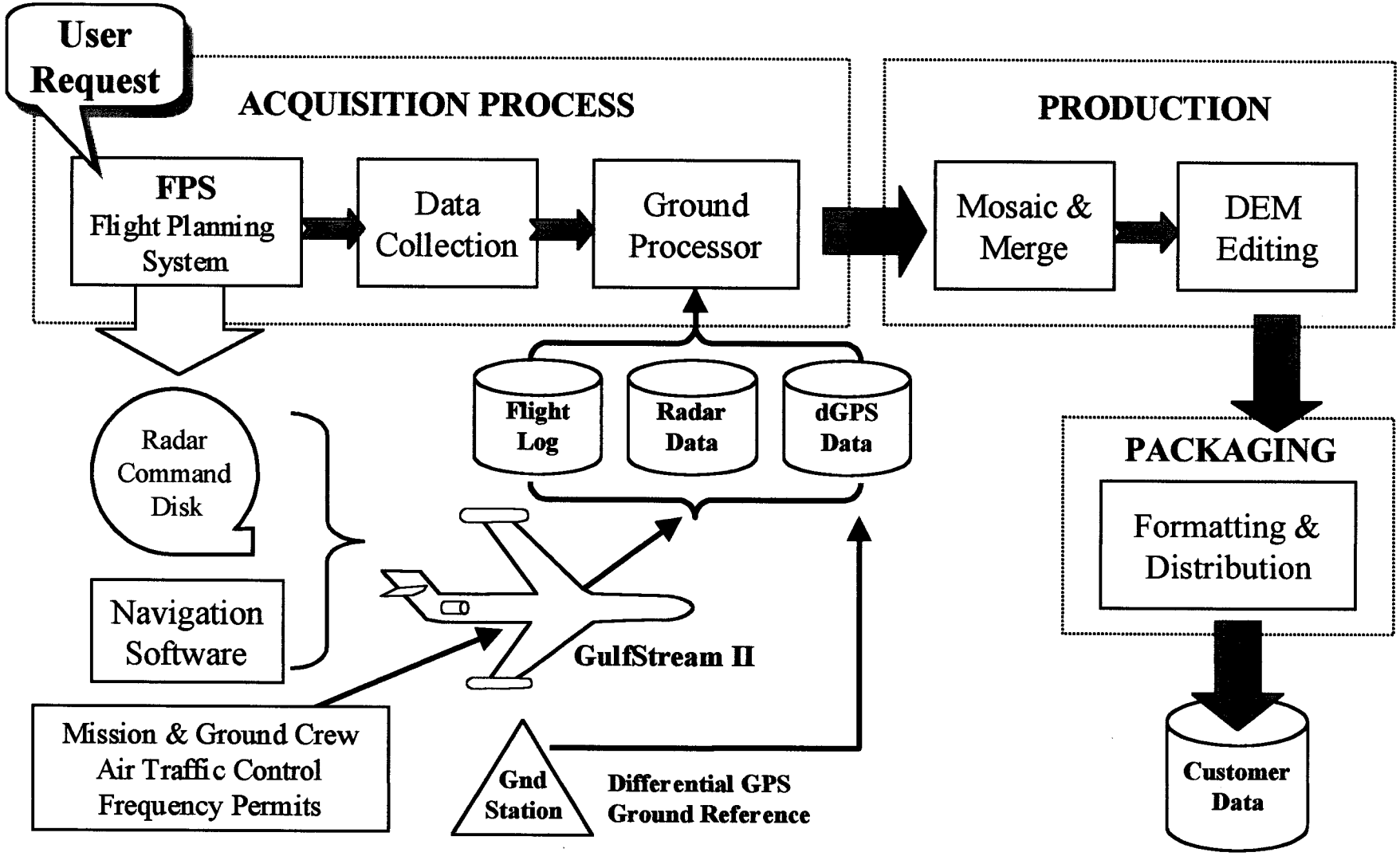

GeoSAR Mapping Specifications

Description	X-Band	P-Band
DEM Height Accuracy (1σ)	0.5 - 1.2 m (Relative) 2.5 m (Absolute)	1 - 3 m (Relative) 2 - 5 m @ 5 km Altitude (Absolute)
Planimetric Accuracy (1σ)	1 m (Relative) 2.5 m (Absolute)	2 m @ 5 km Altitude (Absolute) 4 m @ 10 km Altitude (Absolute)
Ground Swath Width	20 km (Combined Both Sides)	20 km (Combined Both Sides)
Wavelength	3 cm (9630 - 9790 MHz)	86 cm (270 - 430 MHz)
Bandwidth	80/160 MHz	80/160 MHz
Polarization	VV	HH & HV or VV and VH
Baseline Length	2.6 m or (5.2 m Ping-Pong)	20 m and (40 m Ping-Pong)

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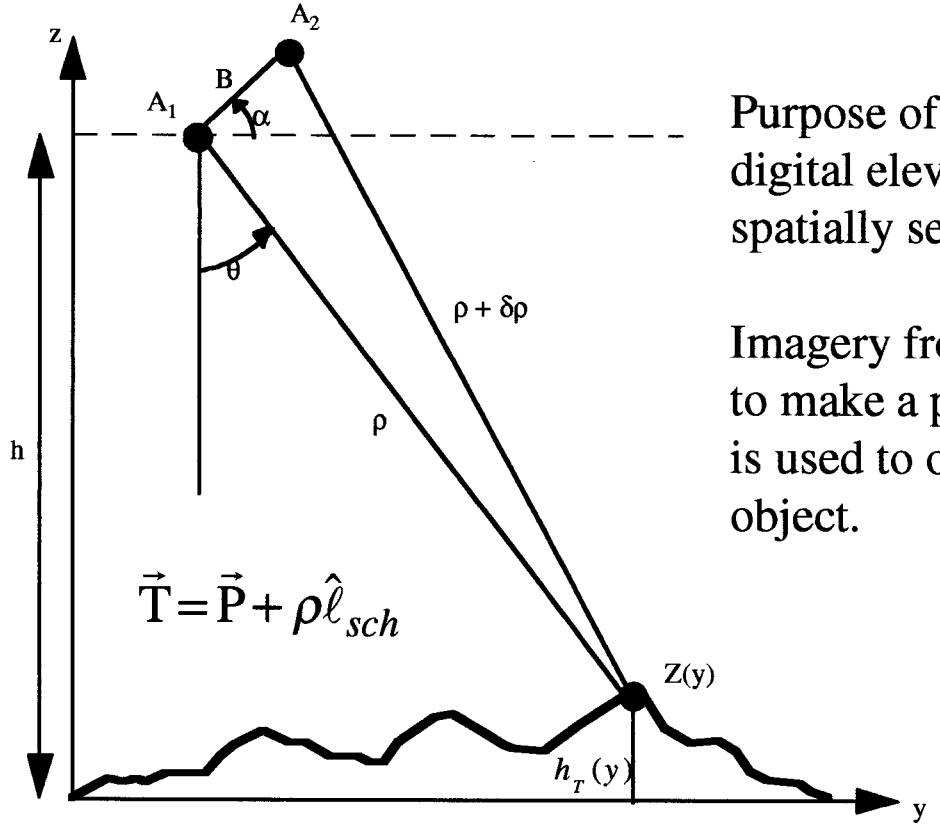
What is radar interferometry?



Purpose of radar interferometric mapping is to produce digital elevation maps from imagery collected from spatially separated antennas.

Imagery from the two antennas is coherently combined to make a phase measurement and the interferometric phase is used to obtain the three dimensional location of an object.

Given θ, the height of terrain is obtained by

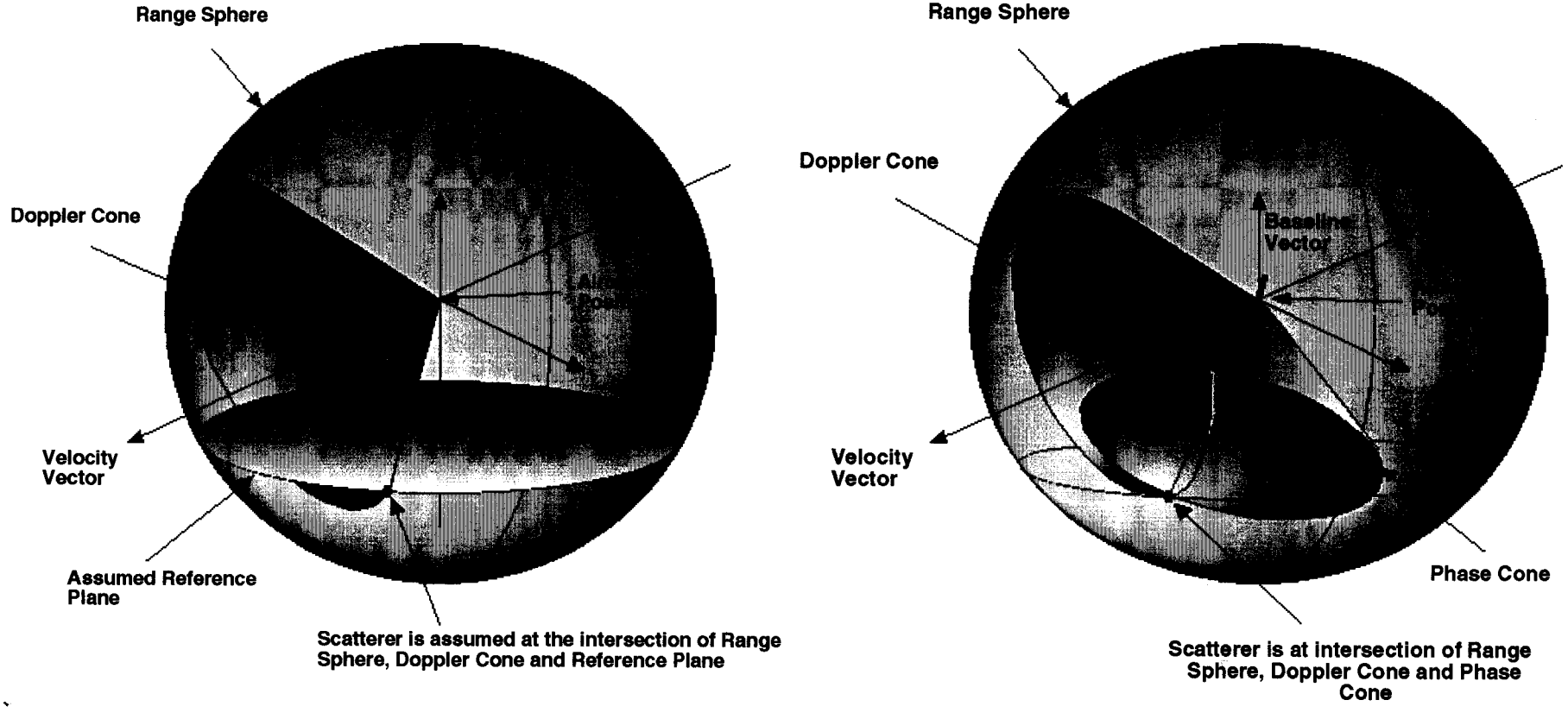
$$h_T(y) = h - \rho\cos\theta$$

The interferometric phase, ϕ, is related to the baseline length b, baseline orientation angle, α, and the look angle, θ by

$$\phi = \frac{4\pi}{\lambda}\delta\rho \approx -\frac{4\pi}{\lambda} b\sin(\theta-\alpha)$$

that may solved for θ, hence used to determine the elevation.

Geometric View of Radar Interferometry



Imaging geometry in traditional (non-interferometric) SAR processing is able to determine the position of an object in two dimensions as shown in the left image. With interferometric SAR the three dimensional position of an object can be determined by using the phase cone to determine the elevation angle to the object.

GeoSAR System Parameter Overview

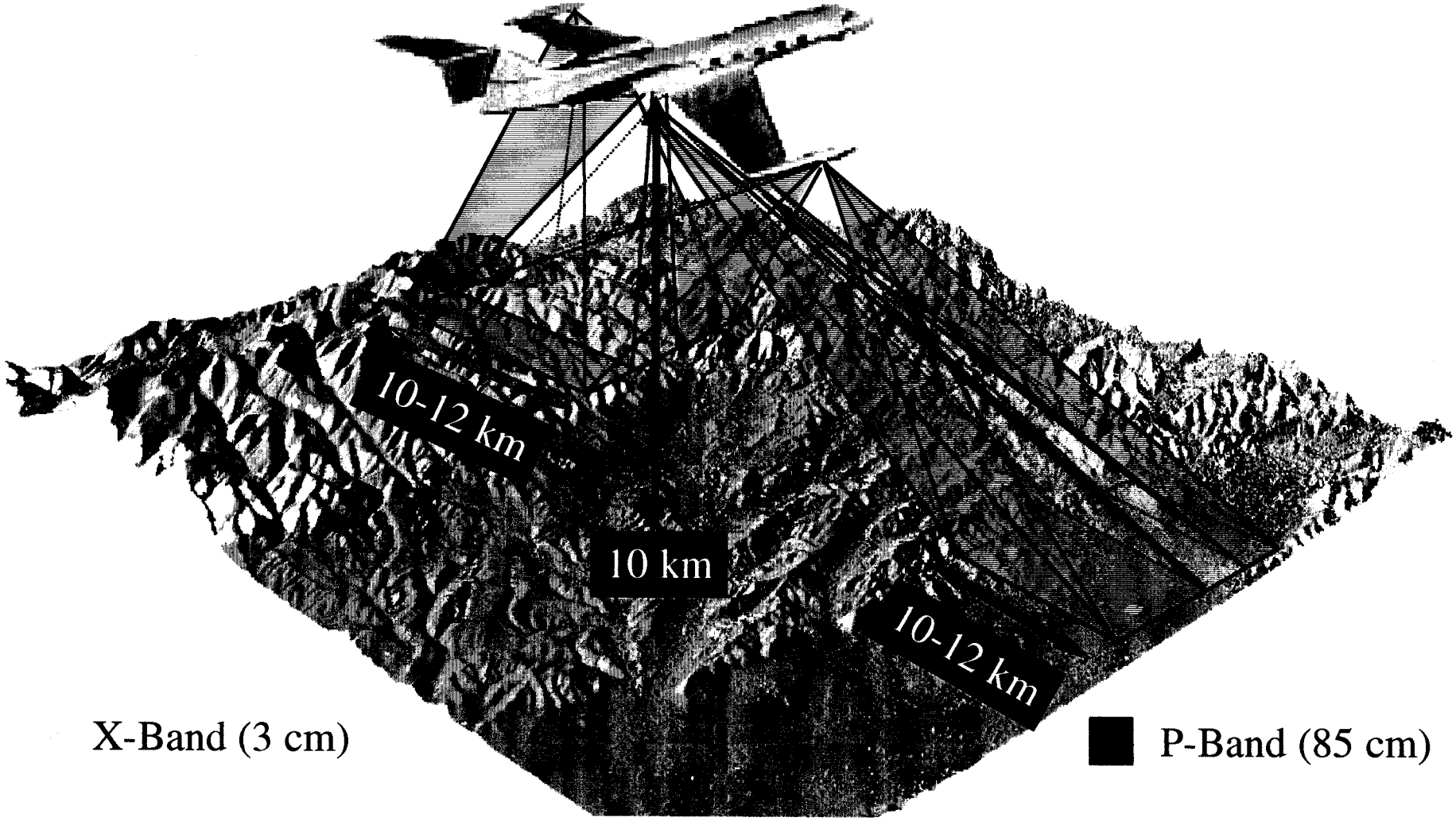
P-BAND SYSTEM PARAMETERS

Parameter	Value
Peak Transmit Power	4 kW
Bandwidth	80/160 MHz
Pulse Length	40 µs
Sampling	8/4 BFPQ@160 MHz 8 Bit @80 MHz
Antenna Size	1.524 m x .381 m
Antenna Gain at Boresight	11 dBi
Look Angle Range	22°-60°
Wavelength	.86 m (160 MHz) / .96 m (80 MHz)
Center Frequency	350 MHz
Baseline Length	20 m and 40 m
Baseline Tilt Angle	0°
Platform Altitude	5000 m -10000 m

X-BAND SYSTEM PARAMETERS

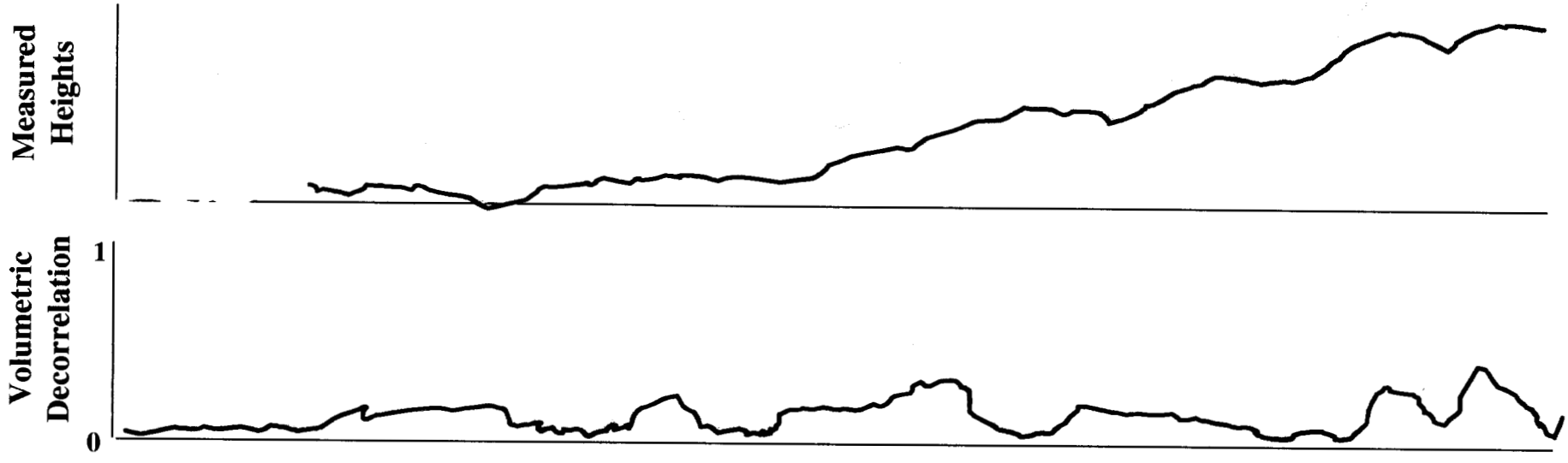
Parameter	Value
Peak Transmit Power	8 kW
Bandwidth	80/160 MHz
Pulse Length	40 µs
Sampling	8/4 BFPQ @160 MHz 8 Bit @80 MHz
Antenna Size	1.5 m x .035 m
Antenna Gain at Boresight	26.5 dBi
Look Angle Range	22°-60°
Wavelength	.031m (160 MHz) / .031 m (80 MHz)
Center Frequency	9.755 MHz
Baseline Length	2.6 m or 5.2 m
Baseline Tilt Angle	0°
Platform Altitude	5000 m -10000 m

GeoSAR Data Collection Geometry

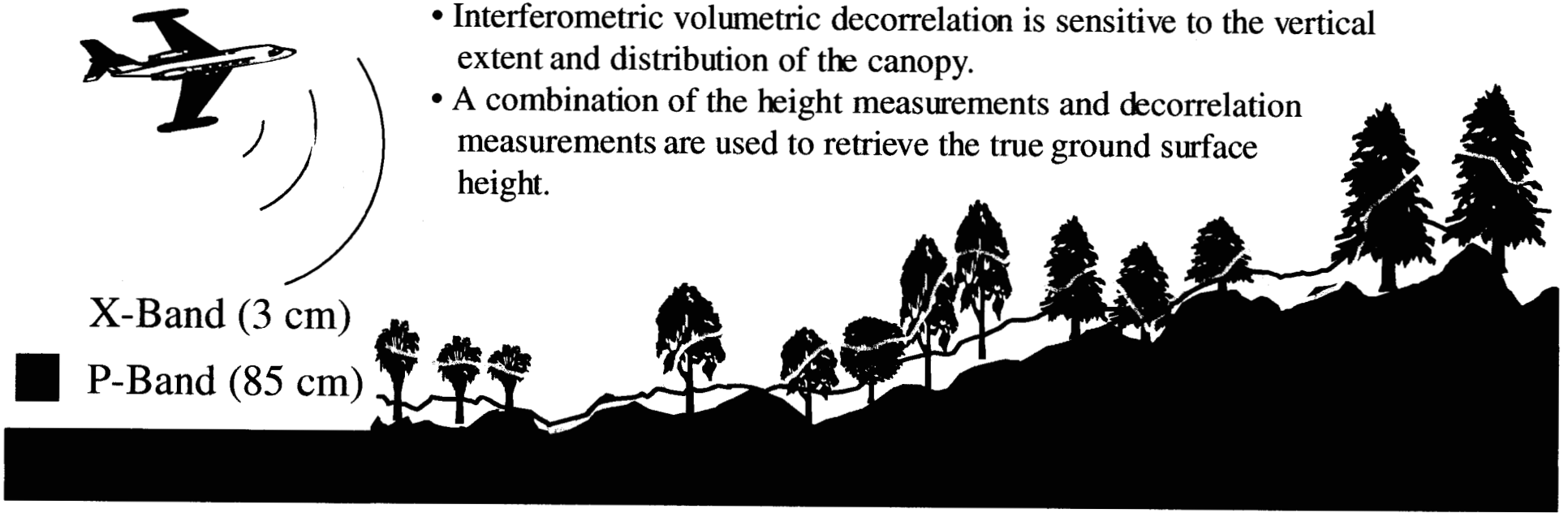


GeoSAR collects interferometric radar data simultaneously on the left and right side of the aircraft for both X-Band and P-Band. The combined data rate for the two radars is 1 Gb/s!

How does GeoSAR work?

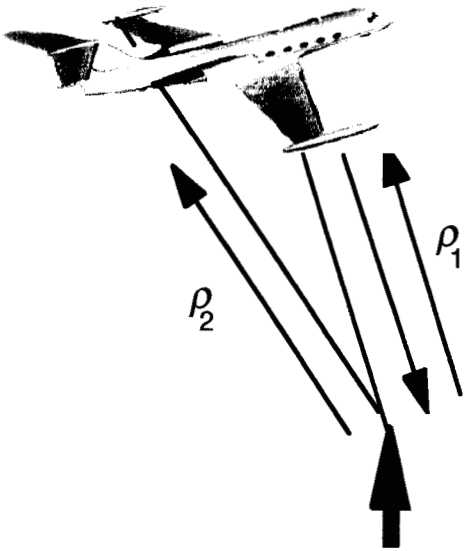


- Lower frequencies (P-band) penetrate deeper into the canopy.
- Interferometric volumetric decorrelation is sensitive to the vertical extent and distribution of the canopy.
- A combination of the height measurements and decorrelation measurements are used to retrieve the true ground surface height.



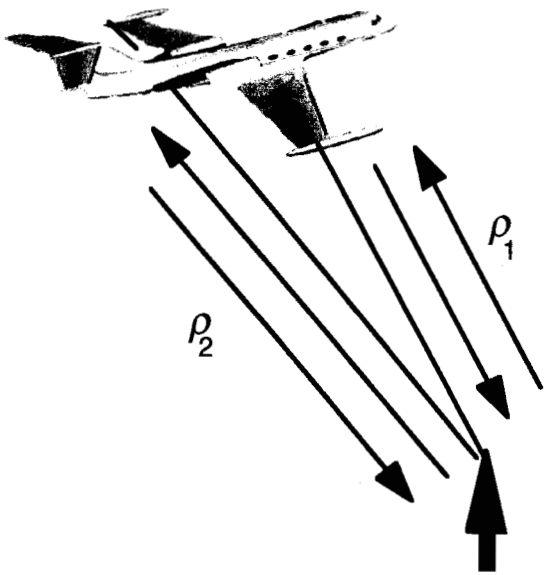
GeoSAR's Two Methods of Data Collection

Single Antenna Transmit



Transmission from one antenna with reception through both antennas simultaneously.

Ping-Pong



Alternately transmitting out of two antennas with reception through the same antenna used for transmission only.

Ping-Pong has an effective baseline that is two times greater Single Antenna Transmit (SAT). Single Antenna Transmit mode can map areas with greater relief than Ping-Pong (PP) mode, however Ping-Pong mode maps with 2 times the height accuracy. GeoSAR can collect X-band data in either SAT or PP mode, P-band simultaneously collects both SAT and PP data.

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Aircraft System Illustration

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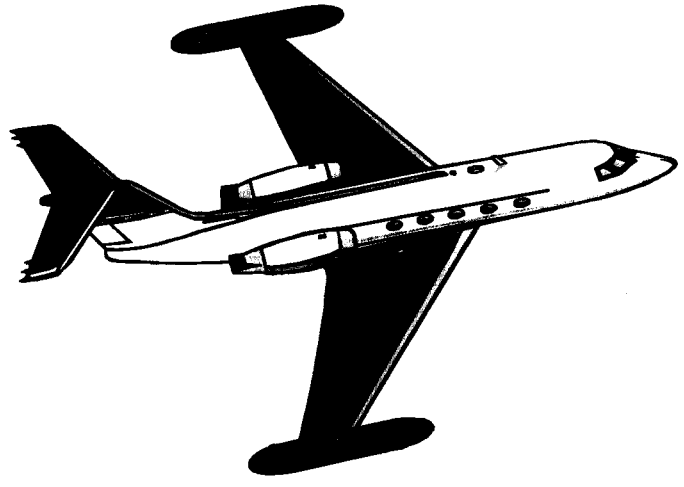
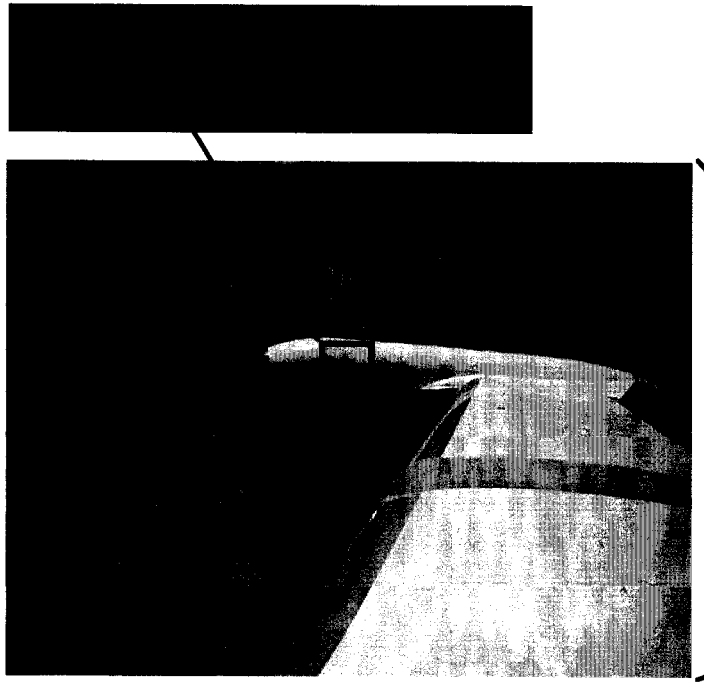
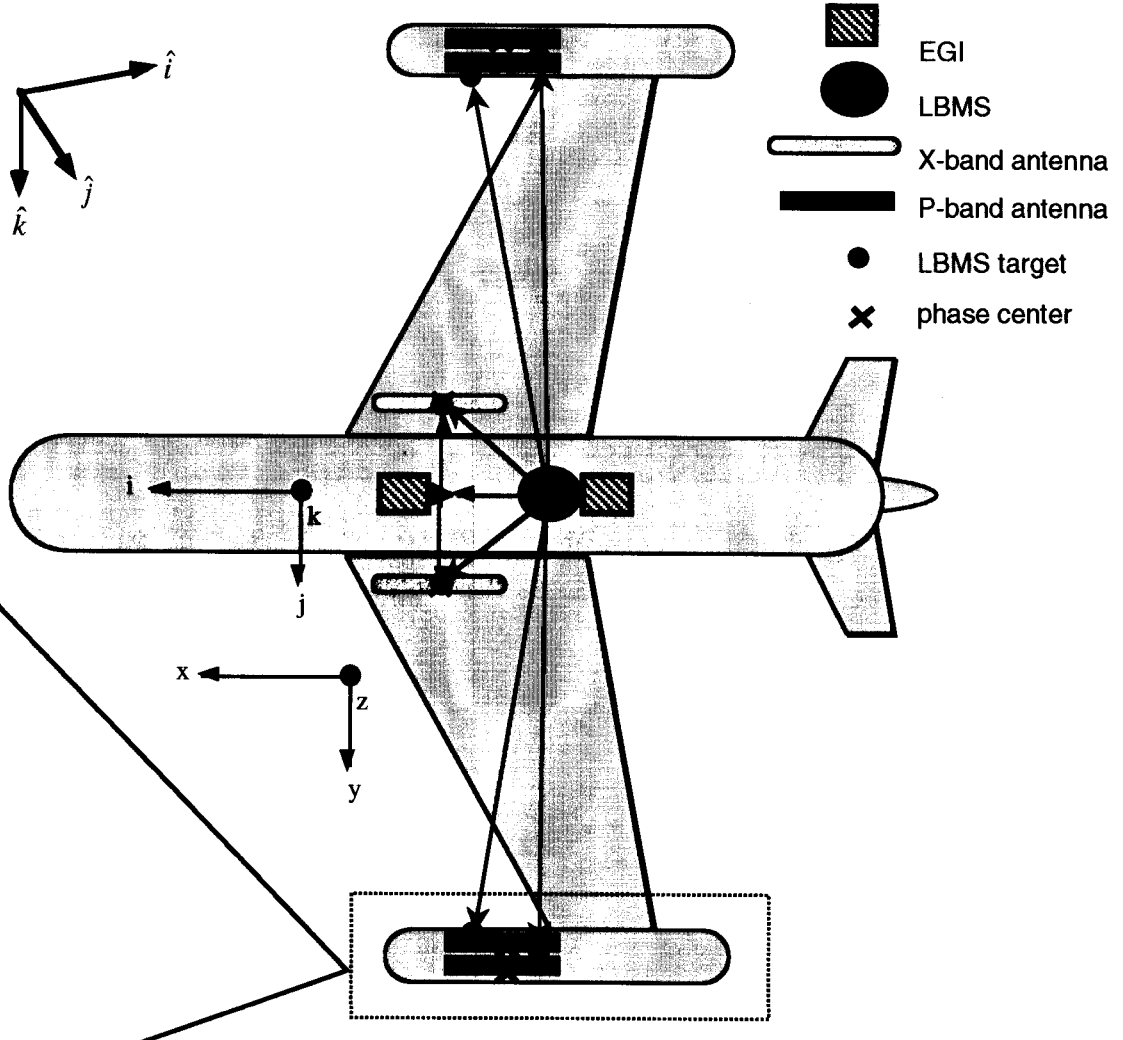




Aircraft, bottom view



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GeoSAR Flight Planning Software

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- Provide the tools to model the geometry and intricacies of GeoSAR data collection.
- Generate the necessary digital interfaces to translate a plan into a mission through the Automatic Radar Controller and Flight Management System.
- Provide pre-mission analysis necessary to:
  - Produce cost-effective flight plans for GeoSAR data collection
  - Make intelligent operational decisions
  - Avoid costly redundant flights due to flight errors

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GeoSAR Flight Planning Software – Screen Capture

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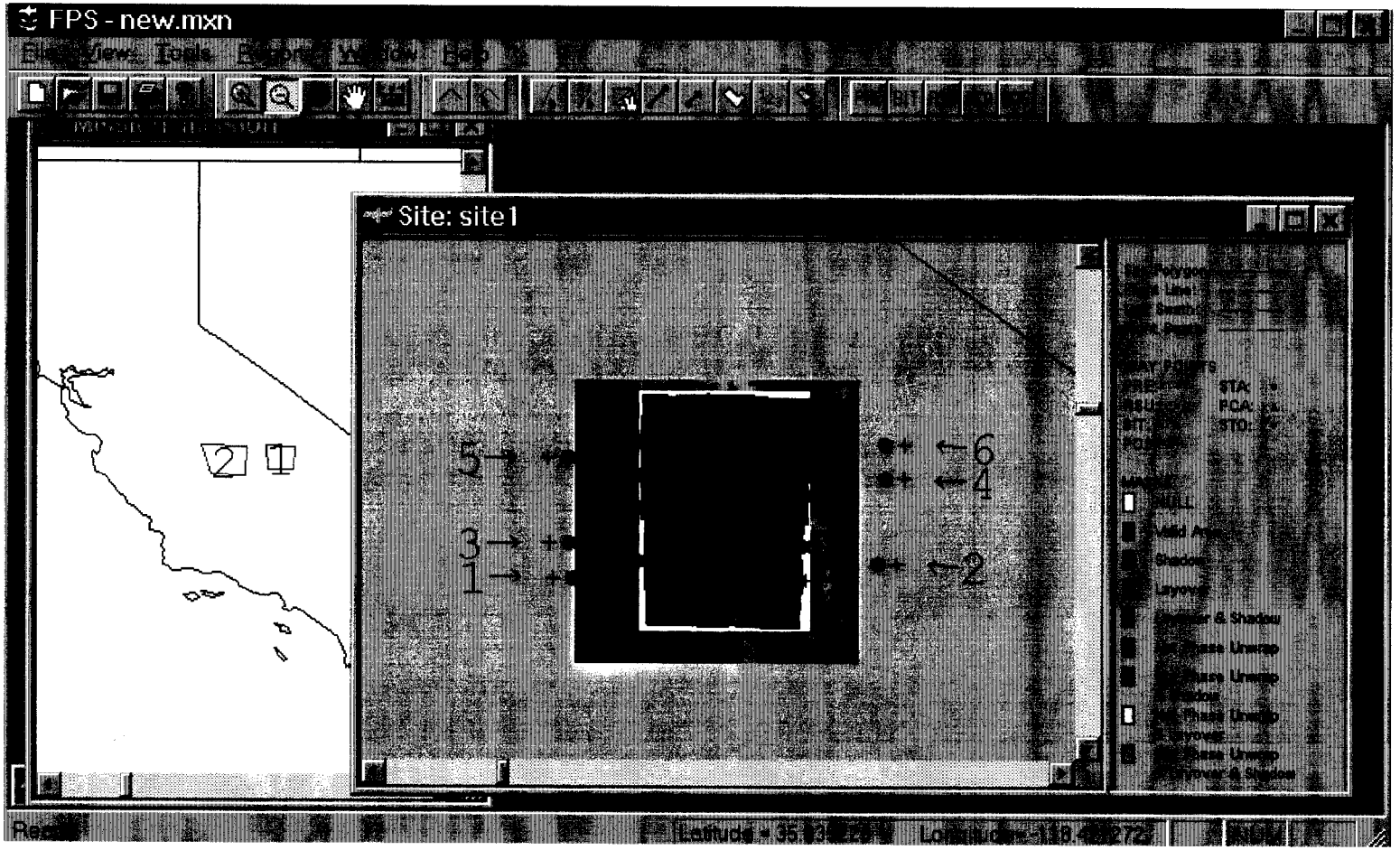

FPS – Layout screen capture.
Mission Area With Mask For Not Phase Unwrappable, Layover, and Shadow Pixels.

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View of GeoSAR Aircraft

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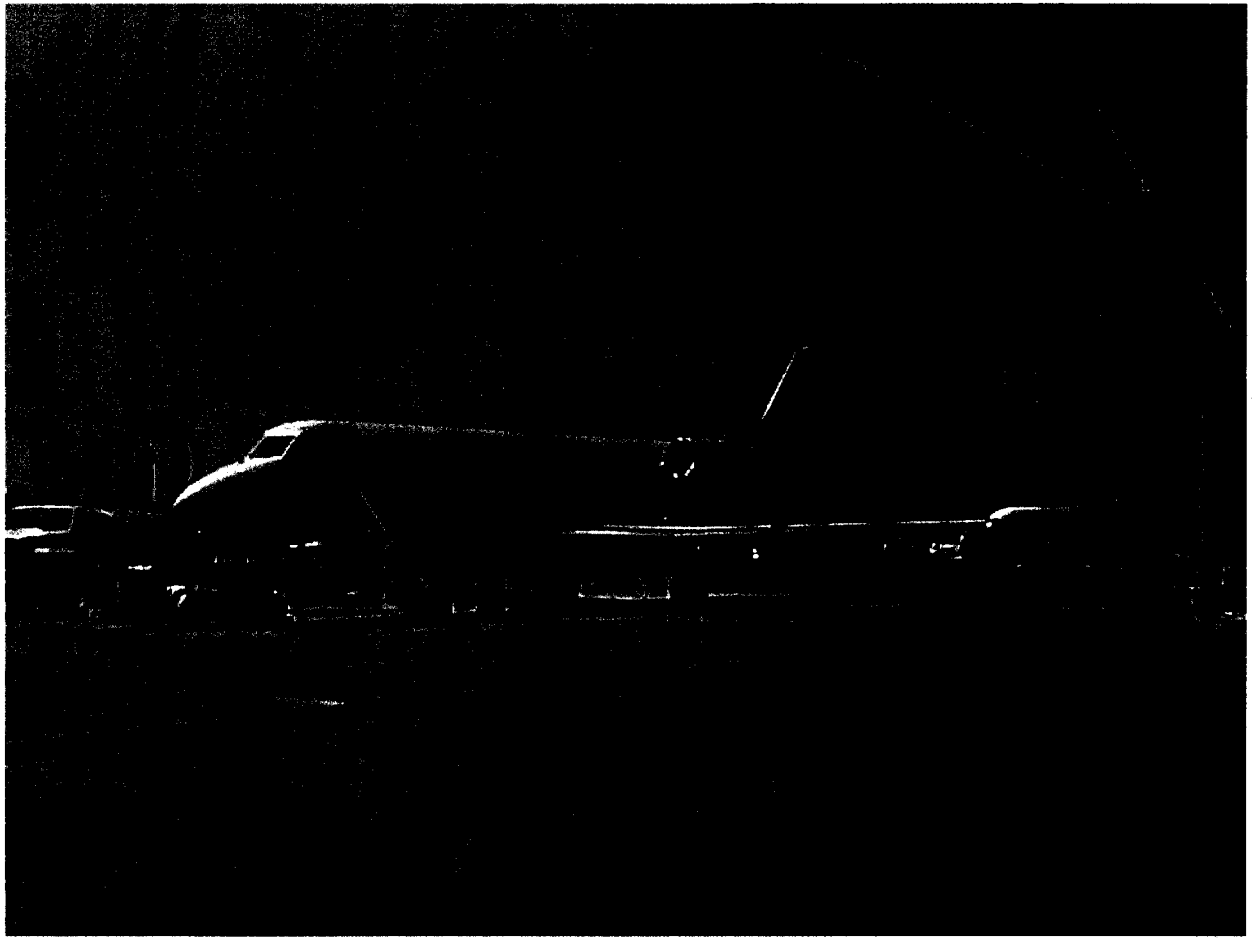

Plane has been modified by TAS at the Van Nuys Airport in California.

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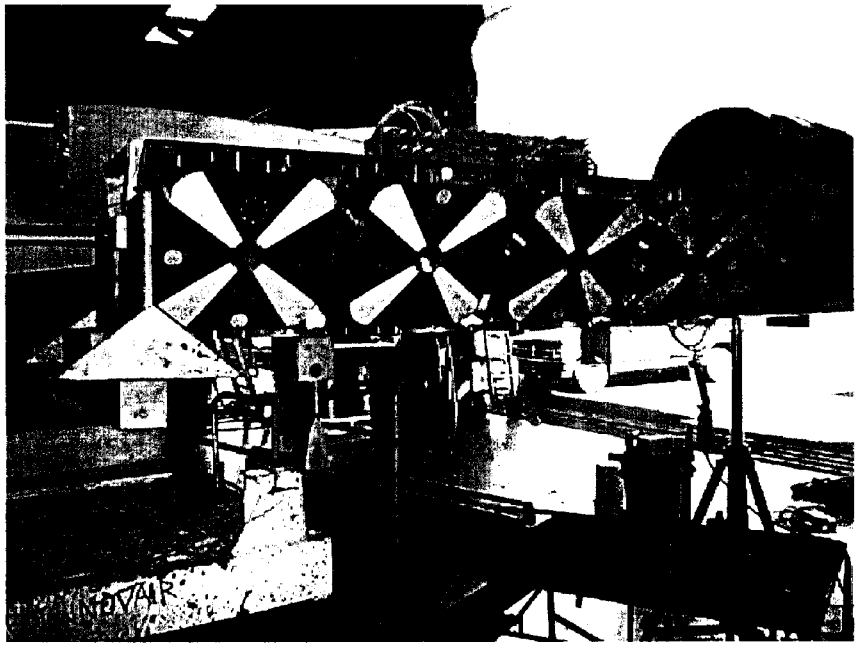
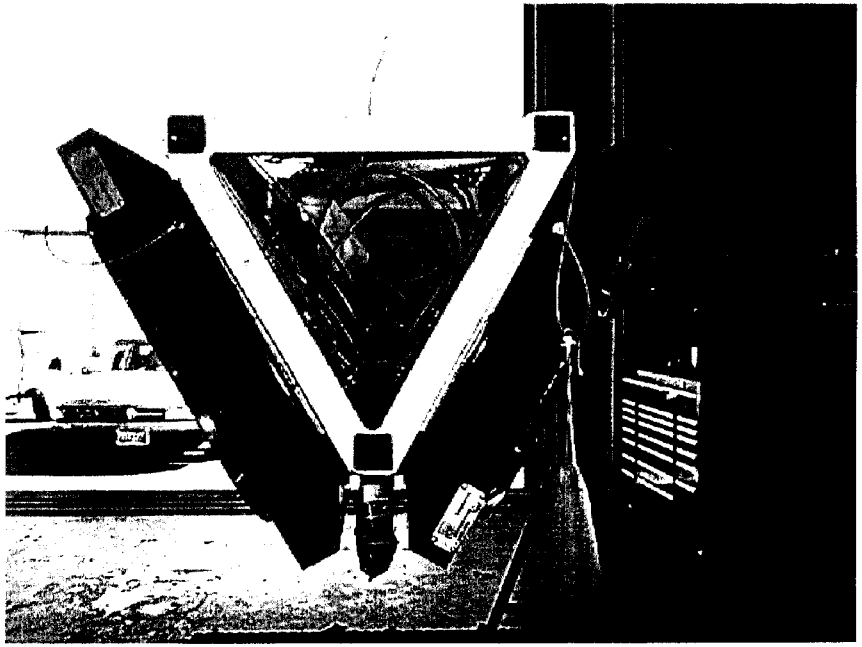
P-band Antennas





P-band antennas are cavity fed micro-strip arrays consisting of four radiating elements. Antennas are designed to operate with 160 MHz of bandwidth at a center frequency of 350 MHz.

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X-band Antenna Fairings

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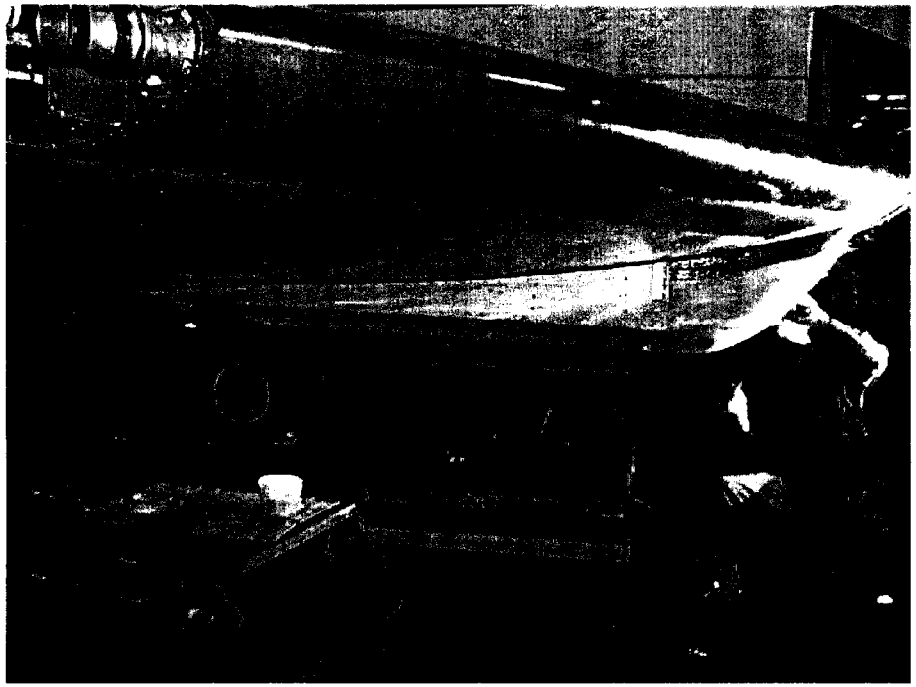
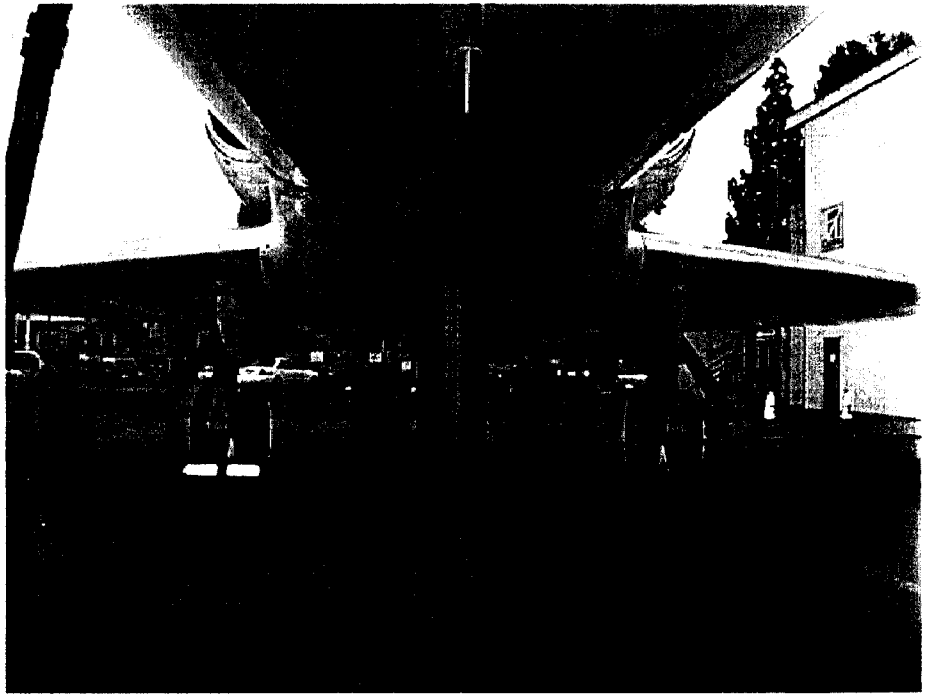


X-band antenna are mounted underneath the fuselage and have a 160 MHz bandwidth at a center frequency of 9.2 GHz.



Front view of the LBMS fairing and X-band antenna fairings.

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GeoSAR Interior View

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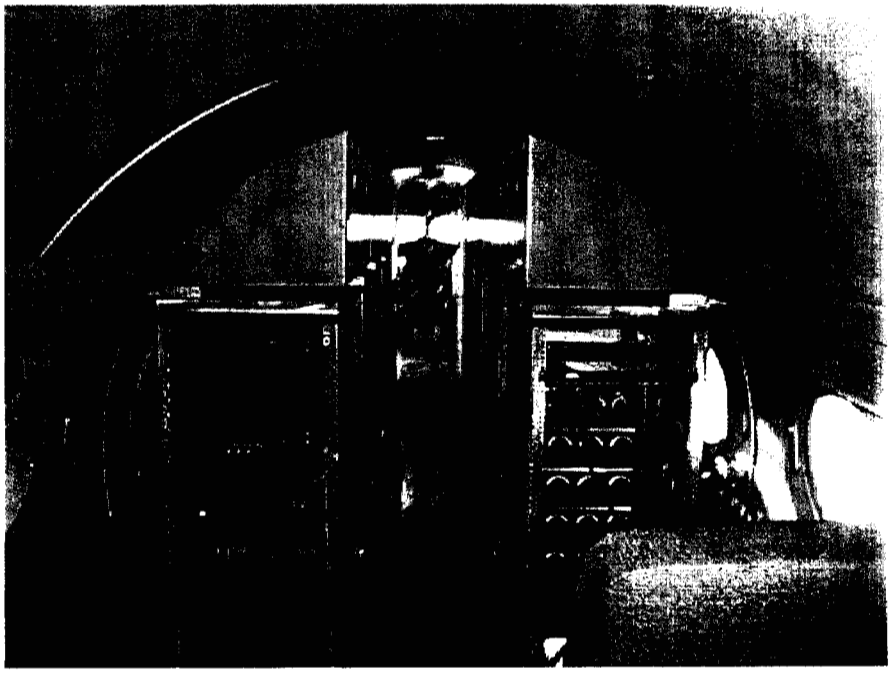

The GeoSAR radar consists of 10 racks. Radar is operated from the Radar operator workstation. Data collection is fully automated. Data collection flight lines and radar operating parameters are generated prior to flight and loaded into the Automatic Radar Controller (ARC) Computer via optical disk prior to takeoff.

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GeoSAR Mapping and GIS Applications

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- Land-use planning
- Analysis of landslides, earthquakes, forest fires, flooding, glacial drift, and other phenomena
- Transportation planning and impact evaluation
- Environmental, forestry, flood plain, and coastline management
- Analysis of biomass and the location and size of trees
- Trafficability analyses with slope at ground level and density of foliage.
- Utility, oil and gas, mining, and agricultural management.

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Potential Products from GeoSAR

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- High accuracy digital elevation models
- Digital terrain models showing ground surface with foliage removed
- Vegetation classifications and tree heights
- Cadastral maps
- Hydrographic models for water management and flood mitigation
- Land-use maps
- 2.5-meter pixel orthorectified SAR imagery

Solvang, California

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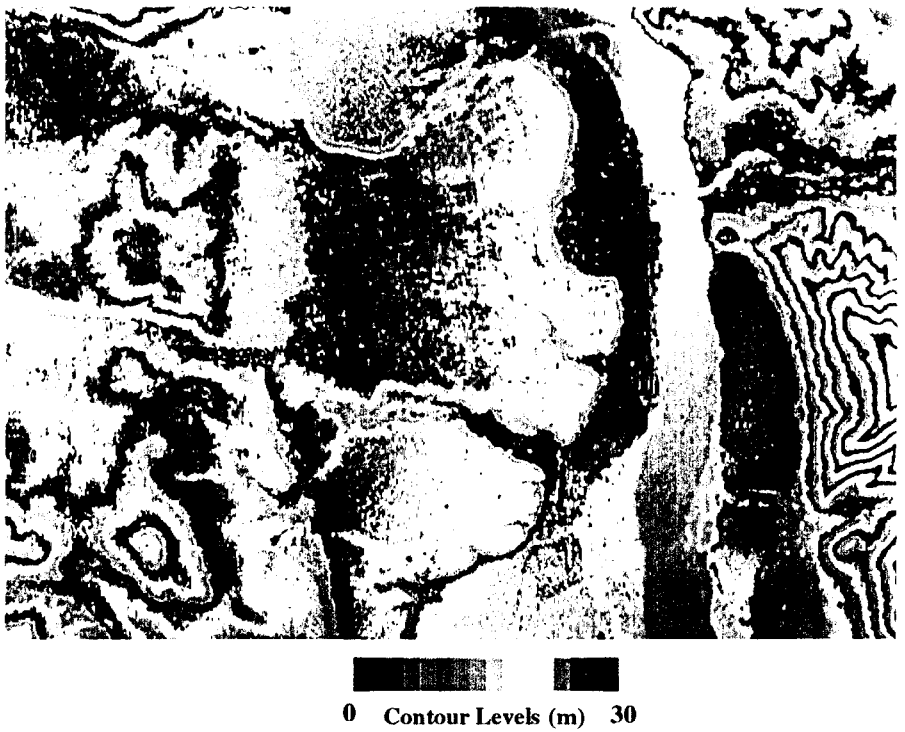
X-Band 80 MHz Radar Brightness Image

X-Band 80 MHz DEM



The left image is a radar brightness image from the X-Band GeoSAR Radar. The right image is a DEM generated from the X-Band SAT mode where elevation is indicated via color contours. The scale at the right indicates that elevation changes 30 m as the color wraps from blue to red and back to blue again. The next slide shows the two images combined with the color contours overlaid on the radar brightness image.

Solvang, California

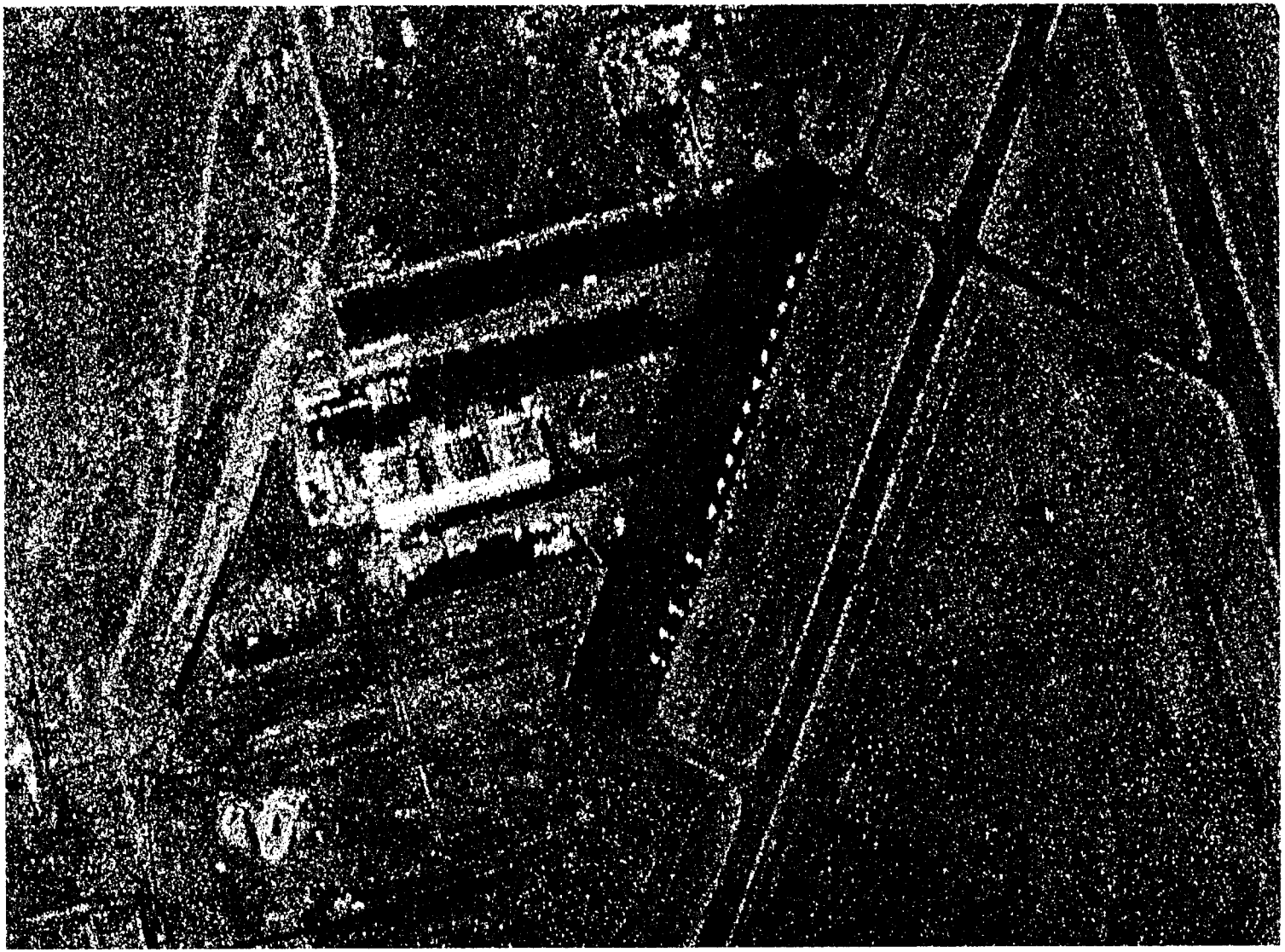
Vandenberg Air Force Base, California

0 Contour Levels (m) 20

Orchards in the Santa Ynez Valley, California

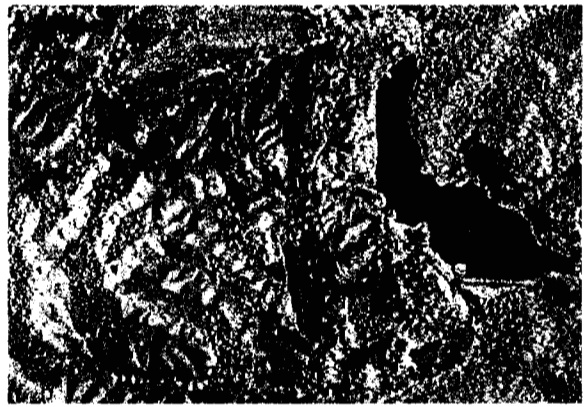
Notice in this 3 m 80 MHz X-band image how each tree can be readily distinguished.

GeoSAR X-Band 160 MHz Bandwidth Image

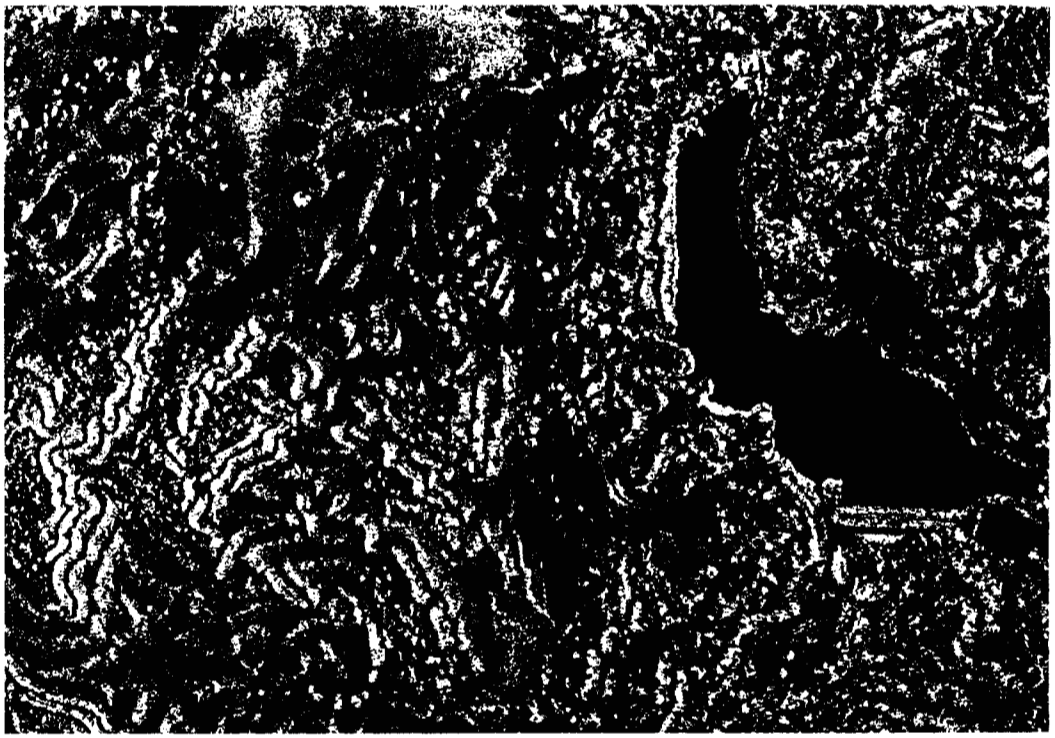


View of Daggett Airport with 15 helicopters clearly visible parked along the airstrip.

Reservoir near Los Padres National Forest



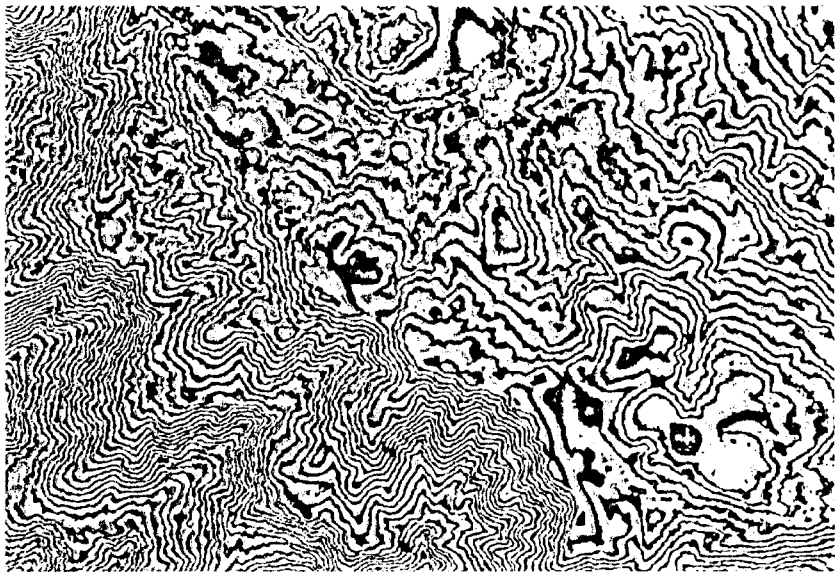
0 Contour Levels (m) 200

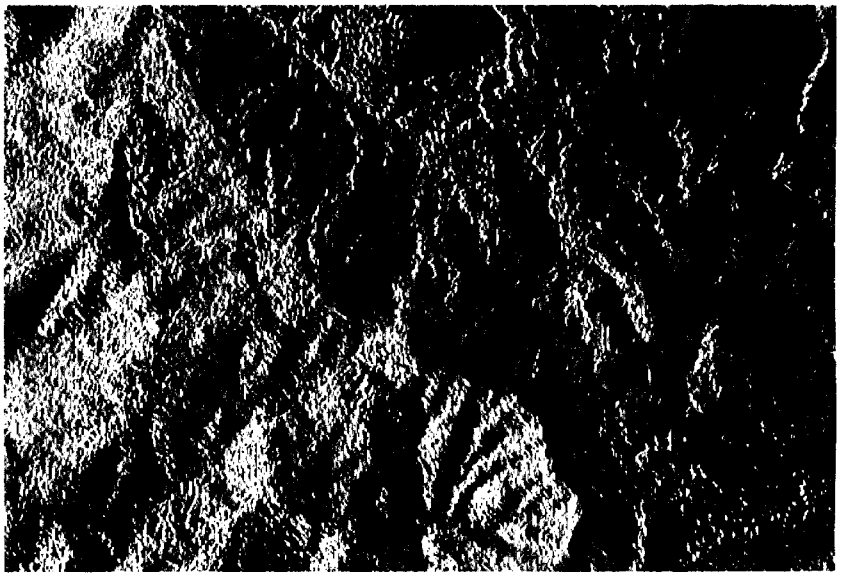


0 Contour Levels (m) 20

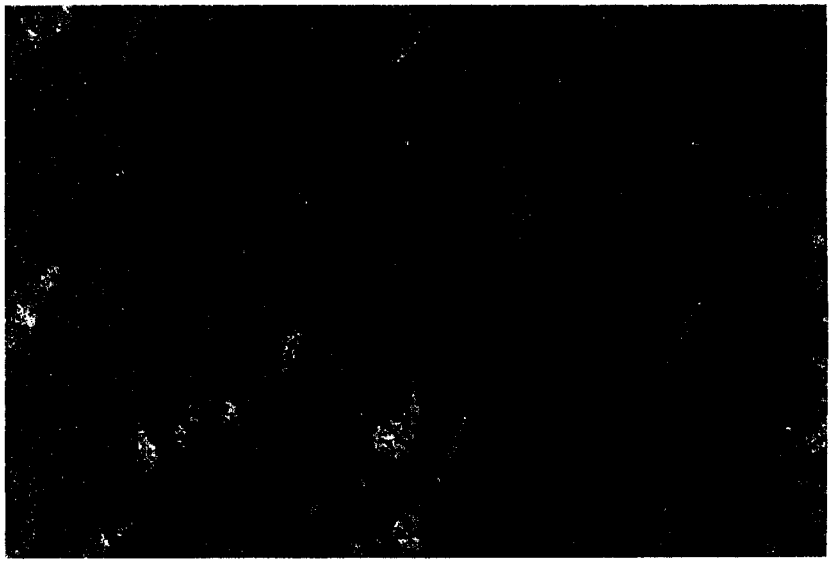
The upper left image is a radar brightness image of an area near a reservoir in Alisal Canyon. Image in lower left has elevation contours overlaid with 200 m color contours that gives the broad area perspective. Elevation contour detail is visible in the right image where a 20 m color contour has been overlaid.

DEM of the Santa Ynez Mountains

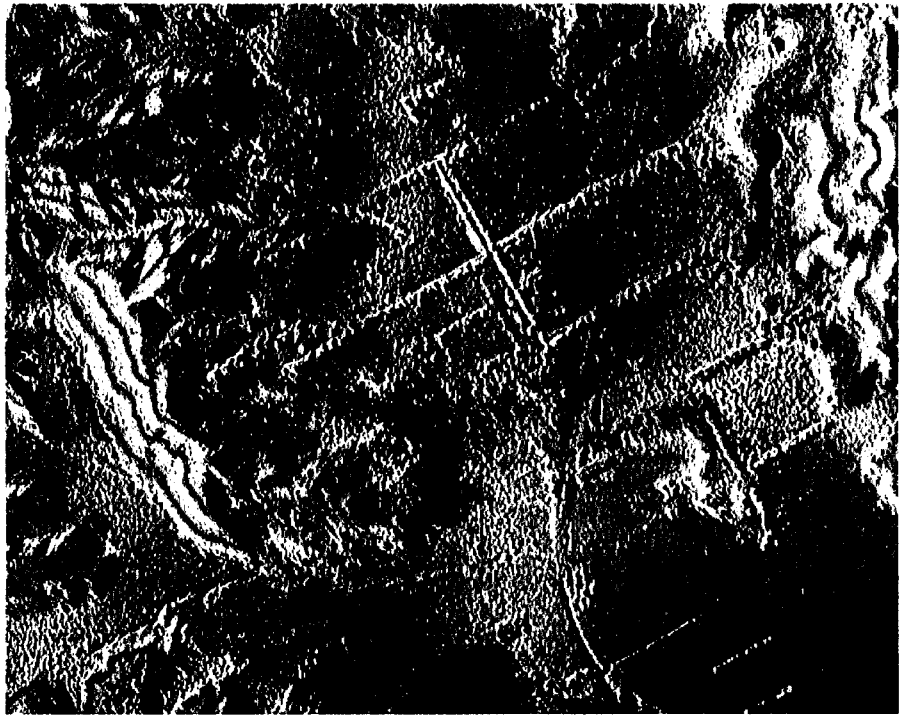




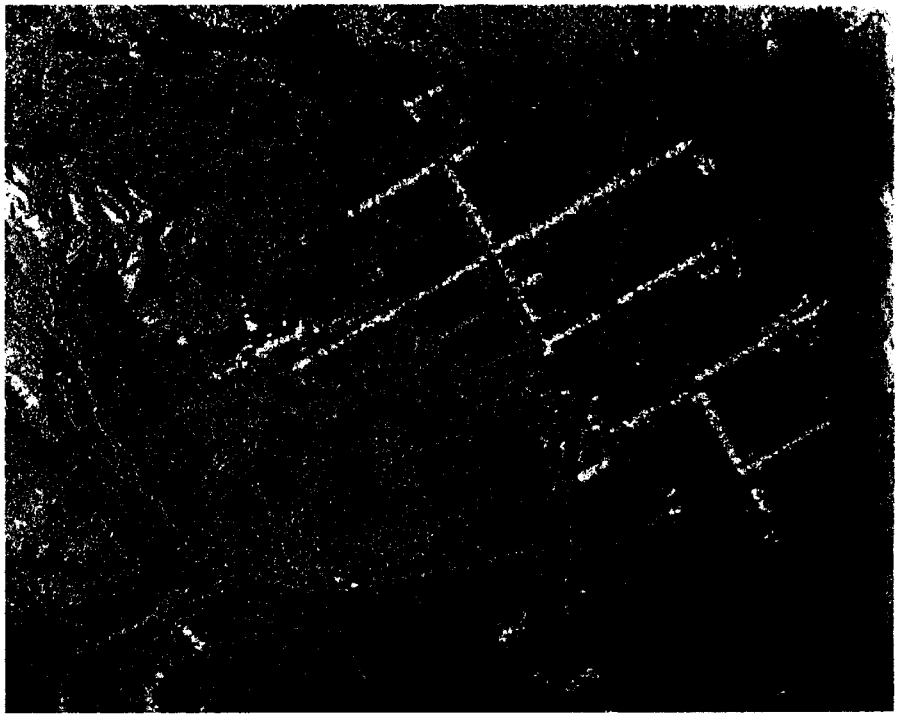
A DEM of the Santa Ynez mountains with 20 m color contouring is shown in the upper left image. A shaded relief image of the DEM is shown to the right. The smooth nature of this image is an indication of the quality of the DEM. The predicted statistical height accuracy shown in the lower left with 1 m contour color wrap also reflects the intrinsic data quality.



Crops Separated by Trees in Santa Barbara County, California



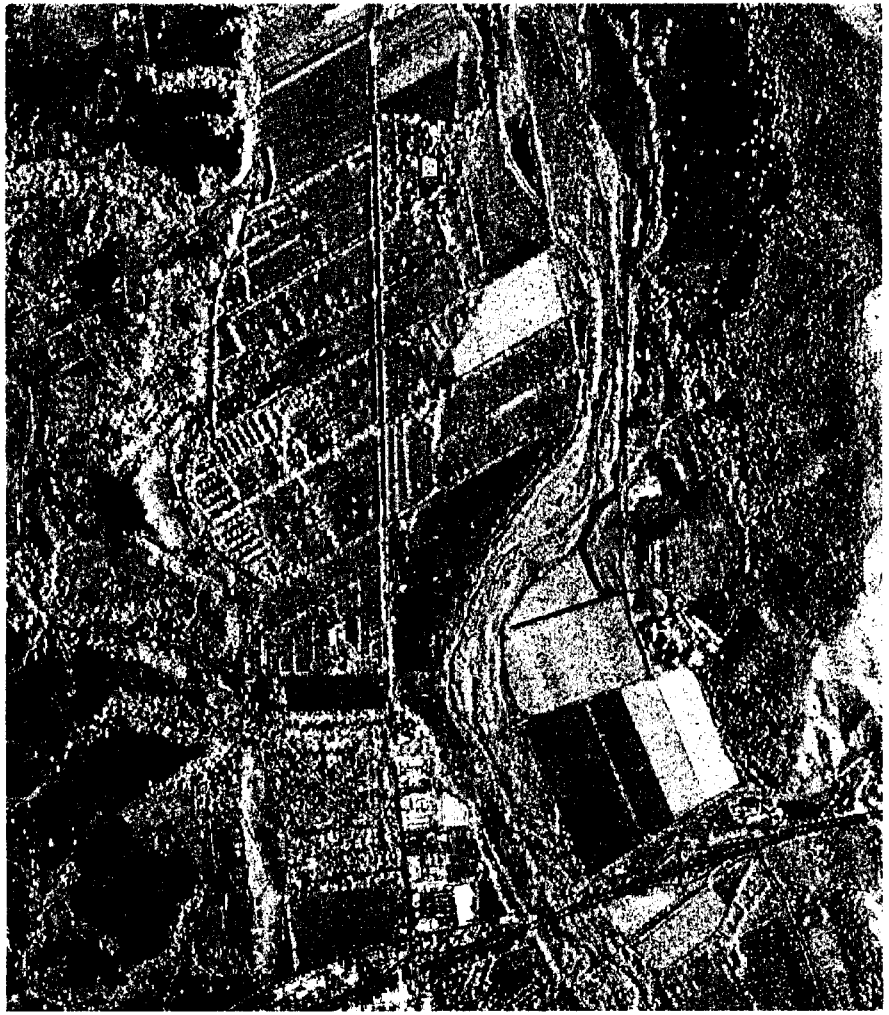
0 Contour Levels (m) 50



0 Contour Levels (m) 1

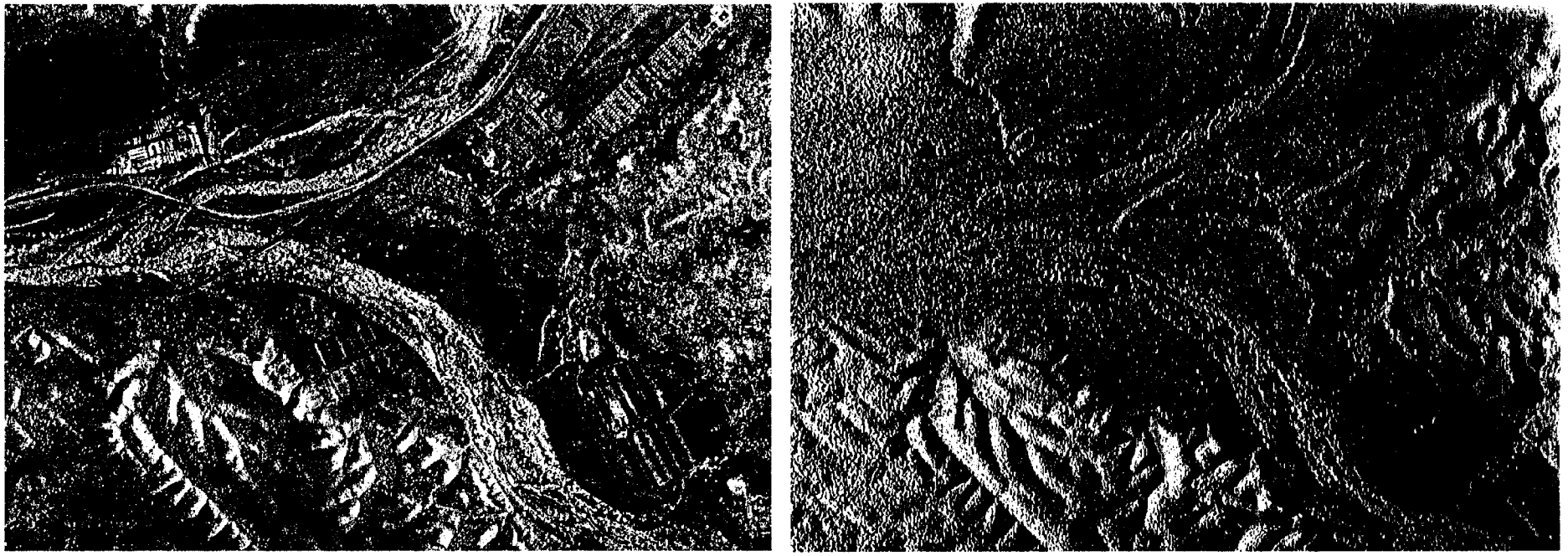
The left image of cropland in Santa Barbara County consists of a shaded relief with 50 m color contouring overlain. The wind breaks (made of a line of trees) are clearly visible in left and right images. The increased height error in the left image is due to volumetric decorrelation, one of the information layers used to derive the true ground surface height map.

Santa Ynez River, California



The left image is an X-Band radar brightness image of the Santa Ynez River and the right image shows the same area in shaded relief with 100 m color contouring overlain. US 101 is the highway visible in the lower portion of the image. Note the riparian regions on the left side of both images and along the Santa Ynez River.

Camp Roberts Military Reservation, California



The left image of Camp Roberts Military Reservation shows the X-Band radar brightness image with color elevation color contours overlain. In the right image the same area is depicted using shaded relief with the same color elevation contours overlain. As illustrated above the combination of shaded relief or radar image with elevation contours can often be an extremely powerful means of visualizing the data.

Camp Roberts Military Reservation, California

0 Contour Levels (m) 20

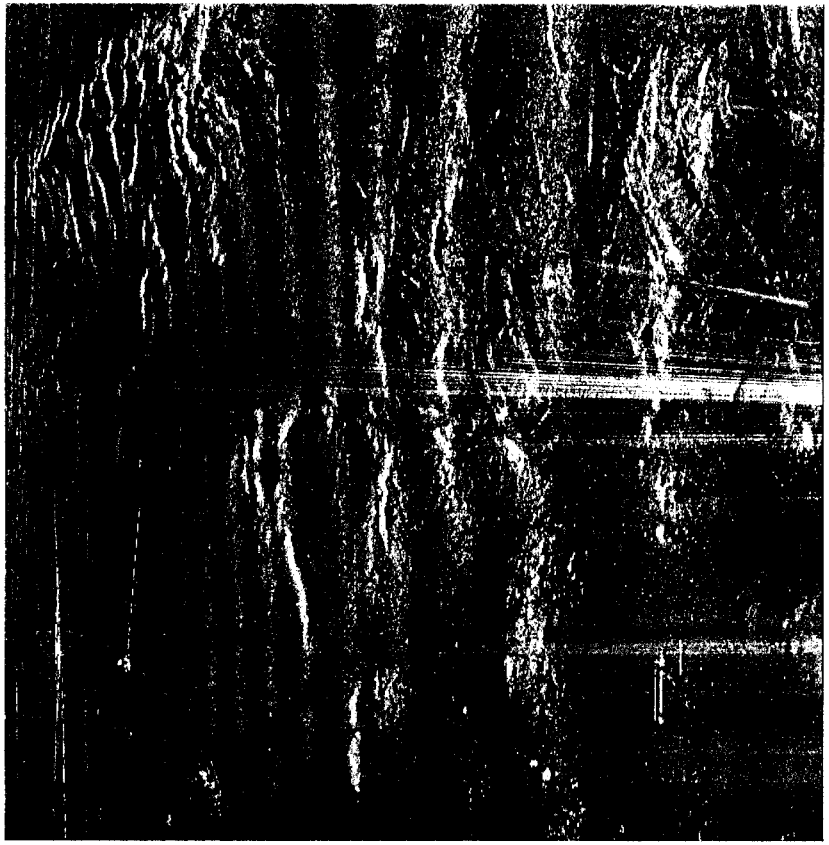
First GeoSAR P-Band Data!

Before RFI Removal

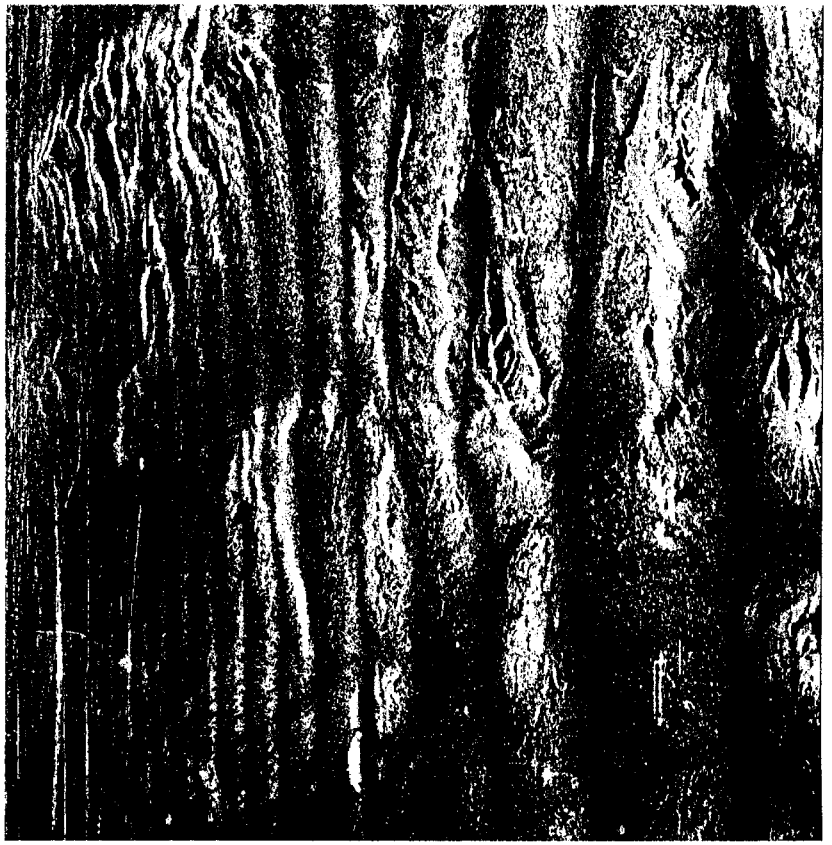
After RFI Removal

GeoSAR 80 MHz Left side P-band data collected at Nevada Test Site on May 7, 2000.

First GeoSAR P-Band Interferogram!



Before RFI Removal

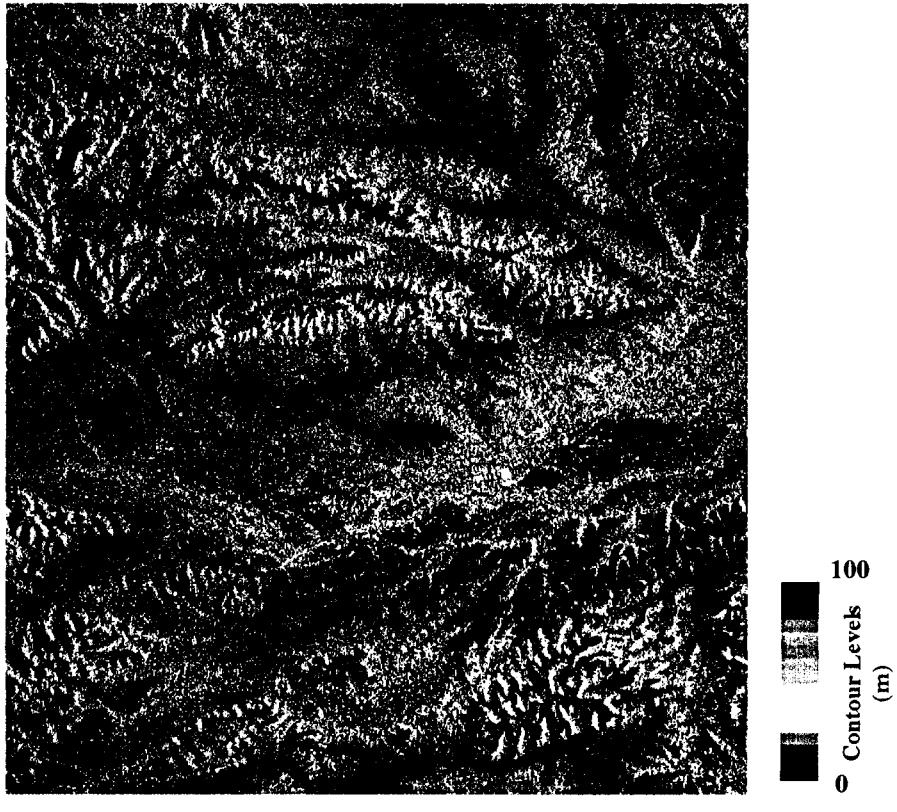


After RFI Removal

GeoSAR 80 MHz Left side P-band interferograms generated from data collected at Nevada Test Site on May 7, 2000.

What's next for GeoSAR?

- Continue development of the GeoSAR into a fully operational commercial system to meet both military and civilian requirements.
- Further refine the GeoSAR system capabilities over diverse terrain and vegetation.
- Enhance commercial GIS software packages to fully exploit the GeoSAR data.
- Evaluate fusion of LIDAR and microwave radiometry with GeoSAR data.



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